RUBEY

# Present Practice In Deep Well Pumping

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# PRESENT PRACTICE

IN

# DEEP WELL PUMPING

BY

HARRY KELLEY RUBEY

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## THESIS

FOR THE

## DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

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May 26, 1905

This is to certify that the following thesis prepared under the direction of Professor A. N. Talbot, Head of the Department of Municipal and Sanitary Engineering, by

HARRY KELLEY RUBEY

entitled PRESENT PRACTICE IN DEEP WELL PUMPING

is accepted by me as fulfilling this part of the requirements for the Degree of Bachelor of Science in Civil Engineering

Ira O. Baker

Head of Department of Civil Engineering

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# PRESENT PRACTICE IN DEEP WELL PUMPING.

An abundant supply of wholesome water is vitally necessary to the modern municipality, and among the many methods of attaining one, that of reaching the underflow through deep wells is most used. In 1897 thirty five per cent of the water works in the United States obtained their supply from this source, and owing to the wide polution of surface waters which has attracted so much attention of late, this percentage will probably increase. Under these conditions the importance of economical ways of raising the water to the surface is evident.

The object of the writer of this thesis has been to present a general summary of the principles which should govern the choice of the kind of pumps which will render the most efficient service under the various conditions and to give some idea of what this efficiency will be. The pumps will be discussed in the following order, (1) Single acting plunger pumps, (2) Double acting plunger pumps, (3) Double acting plunger pumps with quick return stroke, (4) Air lift pumps, (5) Miscellaneous pumps. The information has been gathered principally from descriptions and tests of plants recorded in various engineering periodicals and transactions of societies and consequently represents actual practice. A report of tests made by the writer on the Luitwieler and air-lift pumps at the University of Illinois will be made a part of this thesis.

## THE PUMPING PLANT AS A WHOLE.

The proper combination of pumps and power to produce economical pumping can only be decided for any particular case by a study of the conditions at that place, but a few general remarks concerning this phase of the installation of the plant will be made here for the purpose of showing the various arrangements which have been used.

Steam probably furnishes power to more deep well pumps than all the other sources combined. Electricity and gas are also much used and a few cases of the application of water-power are recorded.

Many pumps are manufactured with the steam engine attached, a combination which minimizes the loss of energy due to the transmission of the power from some comparatively distant source. It also reduces the space required for the pumps, which is sometimes important. The majority of the larger pumps, however, are run by separate engines as by this means much better efficiencies for the steam can be obtained.

Electricity may be used for running deep well pumps and in many cases is economical although the mechanical efficiency may be small. The advantage lies in the fact that little attention is required. At De Kalb, Illinois the pumps are driven by electricity, the regular attendants of the electric plant visiting the pumps twice each day.

Gasoline is used quite extensively and many pumps are now on the market with engines attached. This type of pump can be quickly started and requires but little attendance. Although general opinion usually condemns the gasoline engine as unreliable, not much trouble is experienced with the better makes.

Water power is rarely used as none is usually economically available but some ingenious uses have been made of it. In one case the service pumps were of greater capacity than was required to supply the mains. A new well had been sunk at some distance from the power plant and the water rose to within a few feet of the required level. A centrifugal pump operated by a Pelton water wheel was put in and run by the surplus supply from the service pumps. This arrangement gave an efficiency of about 50% from energy in the water supplied to hydraulic work accomplished. After being used by the wheel the water was not lost but flowed into the storage reservoir.

Aside from the cost of pumping the water, it is usually necessary that some of it is being raised at all times in order to supply the demand. Provision for this is generally made by having auxiliary engines or motors which can run the pumps in case of break-downs or by running the pumps independently from different sources of power. In many cases the water is discharged from the wells into a reservoir of sufficient capacity to allow of shutting down the plant for some time without discontinuing the service.

Two methods have been used of avoiding the low efficiency and inaccessibility of pumps placed in wells. Often the water rises near enough to the surface to be reached by suction and if such is the case the water may be raised by any pump capable of suction. This is hardly a case which is comparable with deep well pumping as it presents none of the difficulties and consequently will not be discussed here.

A rather novel method of obtaining room in which to install a pump below ground so as to secure a good efficiency and ease of inspection and repairs is to sink a pump shaft to the level of the water in the wells and to drive horizontal tunnels from the bottom out to the different wells. The pumps are placed in the bottom of the shaft and connected with the wells by piping through the tunnels. The motive power may be in the shaft also but is usually on the surface and connected by a good system of power transmission to the pump. The advantages gained by this system are high efficiency and ease of inspection and repairs. The chief draw-back is the first cost which is probably high owing to the expense of sinking the shaft and driving the tunnels. A plant illustrating this principle is that installed by Mr. D. W. Mead at Rockford, Illinois. The shaft, 80 feet deep and 12 1/2 feet in diameter was connected with the driven wells by tunnels. Three specially designed centrifugal pumps were placed in the pit and connected with three compound condensing engines on the surface by rope drive. The capacity of the plant is seven million gallons per day and a test of the pumps showed an efficiency under varying loads of 70% to very nearly 75% with the ratio of hydraulic work to indicated horse-power of 65% to 70%, the best results being obtained with high lifts.

SINGLE ACTING PLUNGER PUMPS.

This type of pump consists of a cylinder below the water level in the well which is connected with a steam head or other arrangement for furnishing power on the surface by a wooden pump rod. This is probably the most used form of deep well pumps although it has many mechanical deficiencies. The water is raised only on the upward stroke which causes a low rate of discharge

as the speed at which deep well pump rods are operated is limited by their buckling. The discharge is intermittent and as a result of the variation of the loads from nothing to full load the wear and tear on the pump is excessive. No data were found by the writer concerning the efficiency but it is doubtless much lower than the other types described with a possible exception of the air lift.

The only good point about this kind of a pump is the low first cost. Most of those which are installed at present will probably be replaced by pumps of better design, although in some cases where the amounts of water to be pumped are small, they may still be used to advantage.

DOUBLE ACTING PLUNGER PUMPS.

This pump differs from the single acting plunger pump in that there are two plungers working in the water cylinder, one above another. Valves in the plungers allow the water to pass upward through them but not downward. Except at the dead center one plunger is always rising and carrying with it a column of water. The plungers are connected with a power on the surface by two pump rods, one working inside the other. The advantage of this type over single acting pumps is that the flow is more nearly continuous and that a greater discharge can be obtained from any given size of well. The result of the approximately uniform discharge is the reduction of the strain and wear on the pump. The only objection offered is the greater cost. No data are available as to the efficiencies but under the best conditions they will probably be greater than for single acting pumps and less than for the quick return double acting pumps next described.

## DOUBLE ACTING QUICK RETURN PLUNGER PUMPS.

These are simply modified forms of the ordinary double acting plunger pumps, the design of which is intended to keep the column of water constantly moving and thus to save the energy necessary to start the water and to lessen the depreciation of the pump. The two forms which are now on the market are the Johnson and the Luitwieler, both of which involve the expedient of a slow rising and a quick return of the plungers caused by a specially designed power head.

A great many of this kind of pumps are now in operation and seem to give entire satisfaction. The Johnson pump has given efficiencies of 67% to 72% and the Luitwieler at the University of Illinois which was tested by the writer gave 63%. These efficiencies are probably higher than are obtained with the ordinary double acting pump and this, combined with the marked advantage in easy running and low cost of repairs, gives the pump a decided superiority. As showing the effect of easy running, it was stated by the superintendent of a small city water supply plant that the valves in the double acting pumps were replaced every year but that with the pumps under consideration the valves were examined at the end of a year of service and showed hardly any signs of wear.

## THE AIR LIFT PUMP.

Probably no question connected with deep well pumping is subjected to as much discussion as the air lift and for this reason the theory as well as the practice of this method will be considered.

The air is pumped by a compressor (a), Fig. 1 into a receiver (b) from which it is conveyed into the well through piping (c). The air is discharged at (e),which must be under

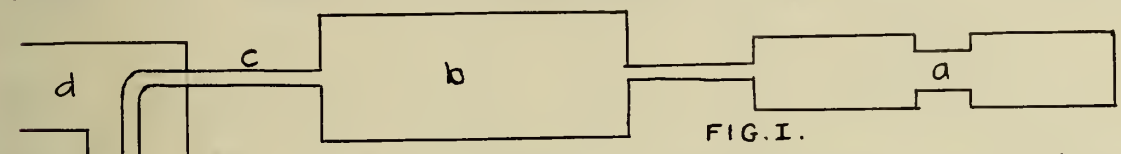
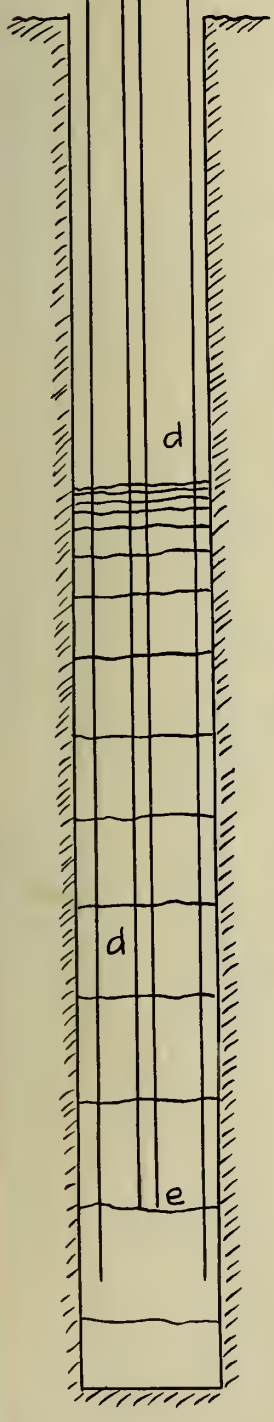


FIG.I.




the water surface, into a larger pipe (d) through which the water and air rise to the surface. When the air is first admitted it probably carries the water upward by an action similar to that of the jet pump but as soon as the water begins to rise a new condition obtains. The water and air arrange themselves in successive layers and,as the specific gravity of the mixture is less than that of water, the column will be forced upward by the buoyant effect of the water in the well to a point at which the weight of the mixture in the pipe (d) will just balance the hydrostatic head at (e).

The most extensive tests of the air lift yet made were those conducted by Mr. B. M. Randall on an experimental well for Dr. Julius Pohle of the Pohle Air Lift Company. Table 1,which is an extract from a more complete table given in the Journal of the Association of Engineering Societies of October 1900, shows the results obtained. The air pipe was 1 inch and the discharge pipe 3 inches in diameter and the efficiencies are the ratio of the hydraulic work to the theoretical energy required to compress the air. Messrs.Brown and Behr

TABLE I

| No. of test | Press in lbs per sq in. in receiver | Temp. in receiver degrees Fahr. | Lift from water surface, feet | Sub. below water surface, feet | Water pumped per. sec.in cu. ft. | Free air per sec.in cu.ft. | Work of com pressing air, ft-lbs | Efficiency of pump, percent |
|---|---|---|---|---|---|---|---|---|
| 1 | 31.1 | 77 | 75.5 | 55.8 | .0799 | 1.09 | 2,616 | 33 |
| 2 | 27.7 | 78 | 75.5 | 55.8 | .1488 | .88 | 1,864 | 38 |
| 3 | 25.6 | 79 | 75.5 | 55.8 | .0824 | .55 | 1,180 | 33 |
| 4 | 30.7 | 74 | 35.5 | 55.5 | .3359 | 1.09 | 2,569 | 28 |
| 5 | 26.4 | 78 | 35.5 | 55.5 | .3105 | .85 | 1,842 | 37 |
| 6 | 24.8 | 78 | 35.5 | 55.5 | .2398 | .55 | 1,155 | 46 |
| 7 | 24.2 | 78 | 35.5 | 55.5 | .1968 | .41 | 834 | 52 |
| 8 | 24.1 | 78 | 54.7 | 36.3 | .1538 | 1.10 | 2,269 | 23 |
| 9 | 17.6 | 78 | 54.7 | 36.3 | .0931 | .65 | 1,072 | 30 |
| 10 | 16.2 | 74 | 54.4 | 36.7 | .0576 | .41 | 636 | 31 |
| 11 | 20.6 | 80 | 63.2 | 27.9 | .0968 | 1.11 | 2,046 | 19 |
| 12 | 18.8 | 76 | 70.1 | 20.4 | .0338 | 1.11 | 1,851 | 8 |
| 13 | 15.3 | 80 | 63.2 | 27.9 | .0663 | .67 | 1,051 | 24 |
| 14 | 12.3 | 79 | 63.2 | 27.8 | .0185 | .35 | 450 | 16 |
| 15 | 12.4 | 79 | 31.5 | 20.0 | .1126 | .62 | 795 | 28 |
| 16 | 20.5 | 69 | 25.3 | 26.3 | .2270 | 1.11 | 2,039 | 18 |
| 17 | 15.8 | 70 | 25.3 | 26.3 | .2026 | .75 | 1,175 | 27 |
| 18 | 12.5 | 70 | 25.3 | 26.3 | .1439 | .41 | 528 | 43 |
| 19 | 22.1 | 72 | 20.3 | 31.3 | .2954 | 1.10 | 2,147 | 17 |
| 20 | 15.2 | 72 | 20.3 | 31.3 | .2270 | .50 | 748 | 37 |
| 21 | 14.5 | 72 | 20.3 | 31.3 | .2146 | .41 | 589 | 46 |
| 22 | 23.1 | 74 | 15.3 | 36.3 | .3593 | 1.11 | 2,209 | 16 |
| 23 | 17.5 | 73 | 15.3 | 36.3 | .3359 | .55 | 911 | 34 |
| 24 | 16.2 | 73 | 15.3 | 36.3 | .2531 | .35 | 550 | 44 |
| 25 | 17.1 | 74 | 36.0 | 15.5 | .0693 | 1.11 | 1,800 | 9 |
| 26 | 10.2 | 74 | 36.0 | 15.5 | .0424 | .62 | 888 | 11 |
| 27 | 7.5 | 73 | 36.0 | 15.5 | .0093 | .33 | 288 | 7 |
| 28 | 15.8 | 76 | 41.0 | 10.5 | .0146 | 1.11 | 1,712 | 2 |
| 30 | 31.7 | 82 | 75.8 | 55.0 | .1799 | 1.11 | 2,685 | 32 |
| 31 | 31.7 | 84 | 75.8 | 55.0 | .1691 | 1.11 | 2,685 | 30 |
| 32 | 25.3 | 84 | 75.8 | 55.0 | .0757 | .52 | 1,091 | 33 |
| 33 | 31.7 | 81 | 75.8 | 55.0 | .1799 | 1.11 | 2,685 | 32 |
| 34 | 31.3 | 80 | 75.8 | 55.0 | .1796 | 1.11 | 2,666 | 32 |

tested this well and in a paper read before the Technical Society of the Pacific Coast in 1890 stated that the greatest efficiencies were obtained when the submergence of the discharge pipe was 67% of the total lift and that with this submergence an efficiency of 50% was obtained. A good many experiments have been conducted in Germany to determine the efficiency of the air lift, but the results fall somewhat short of the percentages obtained in this country. The efficiencies were the ratios of the hydraulic work to the indicated compressor work and ranged from 30% to 45% with a lift of 50 feet and a submergence of 60% to 57%.

As showing some of the better efficiencies which have actually been obtained by this method of pumping the following results are given. The efficiency is the ratio of hydraulic work to indicated engine horse-power.

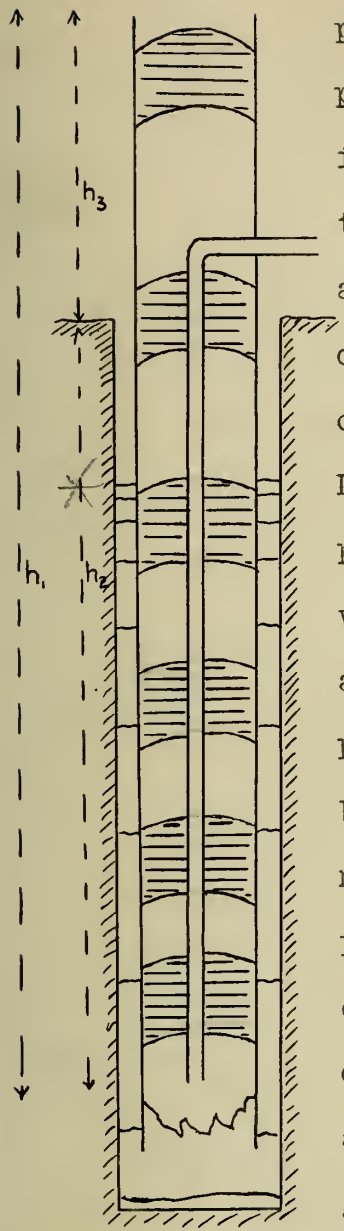
| | |
|---|---|
| At De Kalb, Illinois | 17.5% |
| At Waukesha, Wisconsin | 18.3% |
| At Rockford, Illinois | 20.0% |
| At Rock Island, Illinois | 23.8% |

A formula which is commonly used for determining the amount of air required for a fixed discharge and lift is

$$A = \frac{Qh}{125} \qquad \text{---------- I}$$

where A = cubic feet per minute of free air, Q = gallons per minute of water pumped, and h = lift in feet from surface of water to point of discharge.

As this formula does not agree very well with the results of tests the following has been deduced by the writer. It is assumed that the air leaves the discharge pipe at atmospheric pressure and at the bottom of the discharge pipe it is under the




pressure of a head of water $h_2$ + atmospheric pressure. It is farther assumed that the lifting is due entirely to the buoyant effect of the head $h_2$ . The losses of head due to friction and to the velocity and entrance heads in the discharge pipe are neglected. Under the above conditions the following will hold.

Let n the ratio by volume of free air to water pumped. At the top of the discharge pipe one volume of water will be mixed with n volumes of air. At the bottom the air will be under the pressure $h_2$ + 34 and one volume of water will be mixed with $n \frac{34}{h_2 + 34}$ volumes of air. As the mixture of air and water rises in the discharge pipe the air expands. If the density of the column was the same at all points the expansion of the air would vary directly as the distance above the bottom but the specific gravity is greatest at the bottom and least at the top. Under these conditions the value of the ratio of air to water by volume in the column would be represented by a complicated expression. For simplicity the average value of the ratio will be taken as the mean of the ratios at the top and bottom of the column. This approximation will probably not be far wrong.

Mean value of the ratio by volume of air to water

$$= \frac{n + n\frac{34}{h_2 + 34}}{2} \qquad \text{----------(a)}$$

and the ratio of the water in the column to the total volume

$$\text{of the column} = \frac{1}{1 + \frac{n+n}{2}\,\frac{h_2 + 34}{34}} \qquad \text{----------(b)}$$

The weight of the air in the mixture is very small as compared to the weight of the water and will be neglected. If equilibrium is maintained at the bottom of the discharge pipe equation (c) will hold

$$h_2 = h_1 \frac{1}{1 + \frac{n+n}{2}\,\frac{h_2 + 34}{34}} \qquad \text{------(c)}$$

Solving for n gives

$$n = \frac{2h_3}{h_2\left[1 + \frac{34}{h_2 + 34}\right]} \qquad \text{----------(d)}$$

Table II shows the amount of air as actually used in tests and the amounts as calculated by formulae I and II.

TABLE II

| Reference | Efficiency | Quantity of air in cu. ft. per min. | | | Submergence % | Lift from water surface in ft. |
|---|---|---|---|---|---|---|
| | | Actual | Formula I | Formula II | | |
| Journal of the Ass. of Engr. Soc. Oct. 1900. Page 210 | 40 | 170 | 235 | 97 | 60 | 39 |
| | 27 | 150 | 101 | 50 | 60 | 30 |
| | 30 | 170 | 178 | 60 | 66 | 35 |
| | 33 | 100 | 128 | 39 | 73 | 32 |
| | 45 | 50 | 33 | 24 | 58 | 22 |
| Table I, tests; 3, 7, & 10. | 33 | 33 | 29 | 10 | 42 | 75 |
| | 52 | 24 | 25 | 11 | 66 | 35 |
| | 31 | 24 | 12 | 7 | 41 | 55 |

From the above table it would seem that formula I gives the best results but it would hardly be expected that formula II would give the proper amount of air without allowing for friction and other losses. If the actual quantities of air used be multiplied by the efficiency of the pump, it will be seen that the product corresponds very closely to the amount of air computed by formula II. Owing to a lack of sufficient experimental data this investigation cannot be profitably carried farther.

General opinion seems to point to a submergence of 66% as giving the highest efficiencies. This may be correct but the series of tests from which these conclusions were probably originally drawn failed to show that a test with a greater submergence than 66% was tried. It is reasonable to expect, and formula I indicates, that the efficiency increases with the submergence even beyond 66%.

A study of the different methods of terminating the air pipe in the well, (1) with pipes straight down (2) with a return bend (3) allowing the air to escape from holes near the end of the pipe, shows very little difference in the results obtained.

SUMMARY:- Tests show that a pump efficiency of about 50% can be realized with a 66% submergence and an air pressure slightly greater than that necessary to discharge the air against the head of water $h_2$. It appears from theoretical consideration that the air pressure should be only large enough to discharge the air into the water and that the efficiency will increase with the submergence. In obtaining the quantity of air necessary under given conditions of discharge, lift, and submergence;

formula II, if used with a reasonable allowance for friction and other losses, will give very close results. To use formula I without regard to submergence would probably lead to serious error.

The advantages of the air lift are: (1) that the power can be transmitted comparatively long distances from the compressing plant with very little energy lost; (2) that the operation is simple, the expense of repairs slight, and the flow of the wells may be controlled from the central power plant; (3) that larger quantities of water can be pumped from any given well provided a good submergence can be obtained; (4) that the water is aereated although it is claimed by the opponents of the air lift that the aeration of underground water is unneccessary; (5) that for a large plant the first cost is low. The disadvantages are, (1) low efficiency, (2) depth of well necessary, (3) that the discharge cannot be into a main or tank under pressure.

The air lift is probably the best method of increasing the flow of artesian wells by pumping. The best results have been obtained with deep submergence, small quantities of air, and high velocity of air discharge.

## MISCELLANEOUS PUMPS.

The problem of deep well pumping has not been fully solved, as the highest efficiencies obtained will admit of a good deal of improvement. Several kinds of pumps besides those already mentioned have been tried but not used to any great extent. The Harris air displacement pump consists of two chambers which are alternately filled with water and then with compressed air which forces the water out and upward. A marked improvement over anything yet attempted in this line, is that the air, after driving

out the water, supplies the compressors instead of being discharged into the atmosphere. This pump as usually made, however, occupies too much space to be used in ordinary wells.

Another pump which has been used to some extent is the Wood propeller pump. In this pump a vertical shaft is placed in the well and screw propeller blades are attached to it at intervals at from 3 feet to 5 feet. The shaft is revolved by power on the surface. Along this same line is the centrifugal deep well pump which is simply a vertical centrifugal pump placed in the well tubing. This pump is being developed at the present time and will probably show a good efficiency.

## TESTS MADE BY THE WRITER.

The water supply of the University of Illinois is drawn from three 8 inch wells approximately 150 feet deep. A Downie double-acting steam head pump is in one, a Luitwieler double-acting continuous flow pump serves the second, and an air lift is installed in the third. It was the intention of the writer to make tests determining the efficiencies of each pump but the Downie is working in a well which is nearly dry, so only the latter two were tested.

AIR LIFT TEST:- The level of the water in the air lift well has been lowered by pumping a great deal more than was expected when it was decided to use this method, and as a consequence the submergence is only 15 feet, while the lift from the water surface is 115 feet. Under these adverse conditions it is to be expected that the efficiency realized would be low and this was borne out by the test.

AIR LIFT PUMP AT UNIVERSITY OF ILLINOIS PUMPING STATION

The air is supplied through a 3/4 inch pipe by a double acting power compressor which was run during the experiment by a 15 horse-power electric motor. The motor was belt connected to a heavy shaft, which was in turn belt connected to the compressor. From the compressor the air was pumped into a steel receiver from which it was piped to the well through about 150 feet of 2 inch and 3/4 inch pipe. The smaller size was continued into the well between the discharge pipe and casing and terminates under the lower end of the discharge pipe in a return bend. The discharge pipe is 3 inches in diameter.

In order to find how much air the compressor would give per stroke when working at the rate to be used in the test, all outlets from the receiver were closed and the temperature and pressure of the inclosed air noted. The compressor was then started and the number of revolutions counted. After several minutes running, the compressor was thrown out and the temperature and pressure of the air again noted. The increase of volume was calculated by the formula PV = MRT and divided by the number of strokes which gave the amount of air compressed per stroke.

The measurements of power were all made by Watt meters attached to the feeding wires of the motor. The compressor was first disconnected from the shaft and the power required to run the shafting alone was measured. The pressure in the receiver was brought to the point at which it was to remain through the test. The compressor was started and the air admitted to the well at the same time. The amount of water pumped was determined by measuring the rise in a tank of known diameter. The level of the water in the well was obtained as follows- a 3/8 inch pipe

was run down beside the drop pipe 111 1/2 feet below the surface of the floor and well below the lowest level of the water. Compressed air was slowly admitted to the pipe until it came out at the lower end. The valve at (a), Fig II was closed and the pressure of the confined air was read on a gage at (b). This pressure in feet of water was the submergence of the pipe, h, and the distance from the water level to the surface was l-h. This method was tested by Prof. Marston at the Iowa Agricultural College and found to give accurate results.

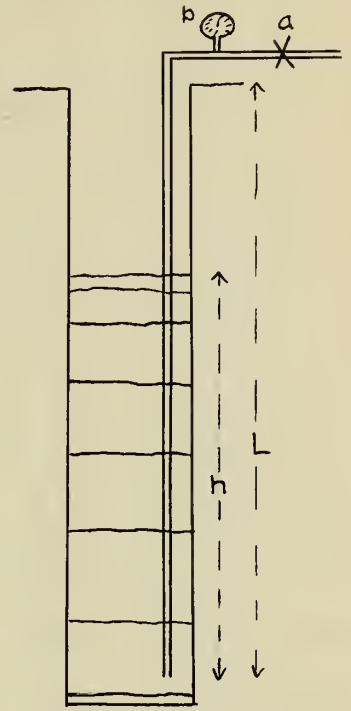


FIG.II.

The data obtained in the test are as follows:-

Volume of water pumped = 3.75 cu. ft. per min.

Weight of water pumped = 234.4 lbs. per min.

Lift, from surface of water in well to point of discharge = 114.9 ft.

Work done by pump = 26932. ft. lbs. per min.

Work done on compressor = 535920. ft. lbs. per min.

Efficiency of pump and compresser = $\frac{26932}{535920}$ = 5%

Amount of air used per cu. ft. of water pumped = 13.8 cu. ft.

THE LUITWIELER TEST:- The Luitwieler pump serves an 8 inch well through a 6 inch drop pipe 121 feet long. Metallic pump rods are used. The working cylinder is 5 3/4 inches in diameter and the stroke is 15 inches. The pump is run by a belt from the shaft which operates the compressor for the air lift. and the same motor was used in the test. The shafting was first run disconnected from the pump and the power used measured. It was then belted to the pump and the power necessary to operate both while running under the conditions of the test was noted. The water was pumped into the same tank as in the air lift test and was measured in the same way. From the pump to the tank the water was forced through about 150 feet of 4 inch pipe having several curves of short radius so that considerable energy was lost in friction. The head lost in this manner was added to the actual lift of the pump and this total was used as the lift for obtaining the hydraulic work accomplished. The number of revolutions of the pump was counted so that the slippage could be computed.

The data obtained in the test are as follows:-

Volume of water pumped = 10.52 cu. ft. per min.

Weight of water pumped = 657.5 lbs. per min.

Lift, from surface of water in well to point of discharge including friction in the pipe from well to reservoir = 109. ft.

Work done by pump = 2.23 horse-power

Work delivered to pump = 3.57 horse-power

LUITWIELER PUMP AT UNIVERSITY OF ILLINOIS PUMPING STATION

$$\text{Efficiency of pump} = \frac{2.23}{3.57} = 62\ 1/2\%$$

Water pumped, measured by plunger displacement 980 cu. ft.

Water pumped, measured in tank 842 cu. ft.

$$\text{Slippage} = \frac{980 - 842}{980} = 14\%$$

## CONCLUSIONS

In general the conditions to which the various pumps are best adapted are as follows:-

(1) Single acting plunger pumps are to be used for small quantities of water and where a low first cost is necessary. The efficiency is small.

(2) Double acting plunger pumps are of better efficiency than the single acting type. They are well adapted for use with a steam head and should be used where the power cannot be economically transmitted except by steam.

(3) Double acting plunger pumps with quick return show the highest efficiencies of pumps placed in wells, discharge the water in a continuous stream, and minimize the wear and tear of plunger pumps.

(4) Air lift pumps are of advantage where the wells are scattered and deep enough for a good submergence. They may be operated from a central plant and require little or no repairs. The efficiencies are probably lower than obtained by the other methods of pumping described. The first cost is low for good sized installations.

(5) Many other forms of pumps are being used but little or no

data concerning them is available.

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